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REFERENCE MODERATOR CALCULATED PERFORMANCE FOR THE LANSCE UPGRADE PROJECT

Phillip D. Ferguson, Gary J. Russell, and Eric J. Pitcher

Manuel Lujan, Jr. Neutron Scattering Center, Los Alamos National Laboratory, USA

ABSTRACT

We have calculated the performance of five moderators of interest to the LANSCE upgrade project. Coupled and decoupled light water and liquid hydrogen moderators in flux-trap geometry surrounded by a neutronically infinite heavy-water cooled beryllium reflector have been studied. Time and energy spectra, as well as semi-empirical fits to the data, are presented. The data has been made available to aid the instrument design and moderator selection process.

1. Introduction

The Manuel Lujan, Jr. Neutron Scattering Center (LANSCE) is currently in the process of an upgrade project. The technical objectives of the project are: 1) improved beam availability to LANSCE, 2) less than 10% downtime from intervals greater than 8 hours, 3) improved capability for routine and sustained operation of LANSCE, 4) personnel access to the LANSCE experimental room #1 (ER-1) with the Proton Storage Ring (PSR) beam on to the LANSCE target, 5) reduced beam delivery operating costs, and 6) reduced radiation exposure [1]. During the upgrade project, the existing target/moderator/reflector/shield system will be replaced and provisions will be made for two additional moderators serving four new flight paths upstream of the upper target. The new moderator types are as of yet undetermined.

The purpose of this work is to present the general moderator performance curves that are being used to determine the LANSCE upgrade project moderator suite. Although the moderator optimization process has not been completed for the LANSCE upgrade project, the moderators presented here do reflect some level of optimization. As such, the results presented here will give reasonable insight into the expected performance of each moderator type. It should be noted that reflector size has a significant impact on the intensity and time distributions from a coupled moderator. For this set of calculations, a neutronically infinite beryllium reflector has been used, resulting in the maximum intensities and broadest pulse shapes from coupled moderators.

Keywords: Moderator, Water, Liquid hydrogen, LANSCE

2. Model Description

The LANSCE Upgrade project Monte Carlo model consists of a singly split tungsten rod target with four identical moderators in flux-trap geometry. A schematic of the model is shown in Fig. 1. A typical poison material is Gd. Depending on the decoupling energy required, Gd, Cd, and ^{10}B or natural B are used as decoupler and liner materials, with Gd decoupling at the lowest energy and B at the highest energy. The Monte Carlo model contains the decouplers, liners, poisons, etc., each of which have a major impact on the neutron time and energy distributions. However, some of the engineering detail, such as the proton beam entry window and the stainless steel reflector canister, are neglected. A more detailed Monte Carlo model will be constructed as the moderator optimization continues, but the current level of model detail provides adequate insight into general moderator performance issues.

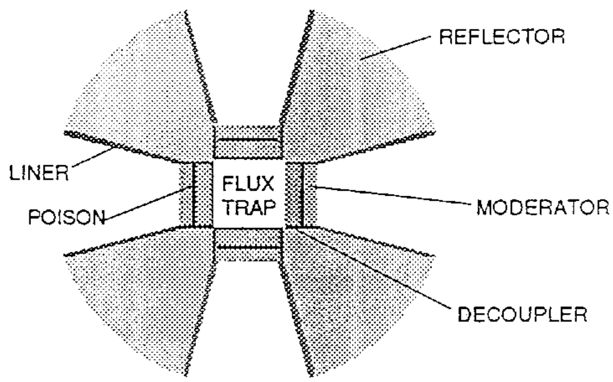

Fig. 1. Schematic of the physics model detailing the locations of the moderators, decouplers, liners, poisons, and reflector.

LAHET Code System (LCS) [2] calculations have been completed for five cases in flux-trap geometry: a) four decoupled high-intensity water moderators, b) four decoupled high-resolution water moderators, c) four coupled water moderators, d) four decoupled liquid hydrogen moderators, and e) four coupled liquid hydrogen moderators. Each water moderator is 3.5 cm thick, and each liquid hydrogen moderator is a 5 cm thick 50/50 mix of ortho-hydrogen and para-hydrogen. Details for each moderator configuration are given in Table 1. For this series of calculations, the reflector was a homogeneous mixture consisting of 85% Be and 15% D_2O by volume. The reflector radius was 75 cm and the height was 150 cm, which approximates an infinite Be reflector.

Table 1. Moderator configurations for the LANSCE 1.5 physics model calculations

	premoderator	moderator	poison	decoupler	liner
high-intensity H_2O	1 cm H_2O	2.5 cm H_2O	0.00508 cm Gd	0.08128 cm Cd	0.08128 cm Cd
high-resolution H_2O	2 cm H_2O	1.5 cm H_2O	0.00508 cm Gd	0.035 cm ^{10}B	0.035 cm ^{10}B
coupled H_2O	none	3.5 cm H_2O	none	none	none
decoupled liquid hydrogen	none	5 cm LH_2	none	0.00508 cm Gd	0.00508 cm Gd
coupled liquid hydrogen	none	5 cm LH_2	none	none	none

3. Energy spectra

Energy spectra for the water and liquid hydrogen moderators are shown in Figs. 2 and 3 respectively. The spectra for the three water moderators were fit using the semi-empirical functional form [3]:

$$E\varphi(E) = E\varphi_{th}(E) + \Delta(E)\varphi_{epi}(E) \tag{1}$$

$$E\varphi_{th}(E) = J\left(\frac{E}{E_T}\right)^2 e^{-\left(\frac{E}{E_T}\right)} \tag{2}$$

$$E\varphi_{epi}(E) = \varphi_{1ev}\left(\frac{E}{1\,eV}\right)^{\alpha} \tag{3}$$

$$\Delta(E) = \frac{1}{1+e^{\left(\frac{a}{\sqrt{E}}-b\right)}} \tag{4}$$

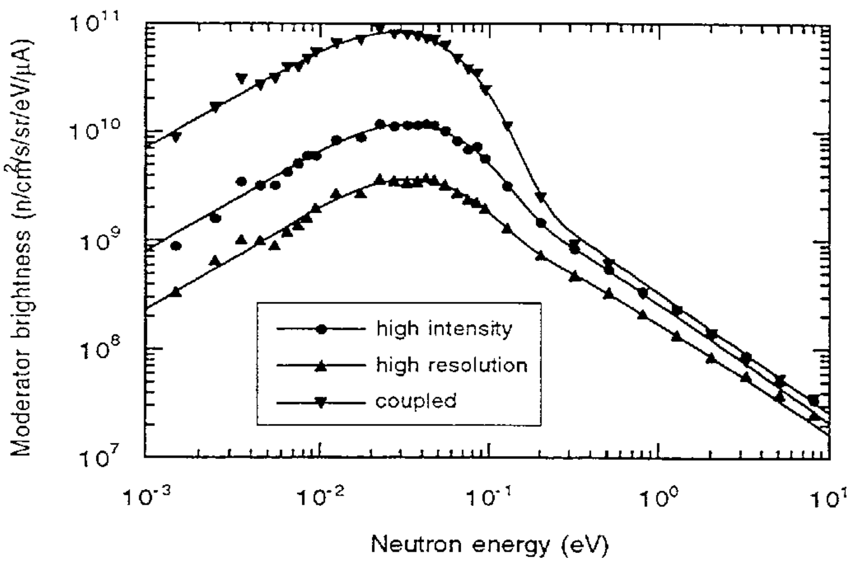

Fig. 2. Average moderator brightness as a function of neutron energy for three water moderators.

Parameters for the water moderator energy spectra fits are presented in Table 2. For an ideal infinite moderator (i.e. no absorption), the slope of the brightness per unit energy near 1 eV is expected to be 1/E [4]. In Fig. 2, the slope is negative for the water moderators due the fact that the moderators are finite and absorbing over the energy range shown. However, the slope is less negative for the high resolution moderator due to the 1/v absorption of the ^{10}B decoupler which preferentially allows more high energy neutrons into the moderator.

Table 2. Fitting parameters for the water moderators

Moderator	J (10^8 n/cm^2/s/sr/μA)	E_T (meV)	$\varphi_{1\,eV}$ (10^8 n/cm^2/s/sr/μA)	α	a ($eV^{0.5}$)	b
High-intensity	7.3	30	3.2	-0.12	0.7	2.2
High-resolution	1.9	28	2.3	-0.05	0.6	1.7
Coupled	53	27	3.2	-0.11	0.7	4.5

The decoupled and coupled liquid hydrogen energy spectra were fit using the semi-empirical functional form [5]:

$$\varphi(E) = \varphi_{th}(E) + \theta_{cut}(E)\varphi_{epi}(E) \tag{5}$$

$$\varphi_{th}(E) = J\frac{E}{E_T^2}e^{-\left(\frac{E}{E_T}\right)} \tag{6}$$

$$\theta_{cut}(E) = 1 - e^{-x}\left(1 + x + 0.5x^2\right)$$
$$x = \begin{cases} 0 & E < E_{cut} \\ \beta(E - E_{cut}) & E \geq E_{cut} \end{cases} \tag{7}$$

$$\varphi_{epi}(E) = \rho(E)\frac{\varphi_{1\,ev}}{E}\left(\frac{E}{1\,eV}\right)^{\alpha}$$

$$\rho(E) = 1 + \delta e^{-y}\left(1 + y + 0.5y^2\right) \tag{8}$$
$$y = \begin{cases} 0 & E < E_{\rho} \\ \gamma\left(E - E_{\rho}\right) & E \geq E_{\rho} \end{cases}$$

Parameters for the liquid hydrogen moderator energy spectra fits are presented in Table 3. The J integral accurately predicts the difference in the Maxwellian peaks, while φ_{1eV} and α reflect the similarity in the two curves above 0.1 eV. The J integral will be lower for a decoupled moderator which uses Cd for a liner material.

Table 3. Fitting parameters for the LH_2 moderator

moderator	J (10^9 n/cm^2/s/sr/μA)	E_T (meV)	φ_{1eV} (10^8 n/cm^2/s/sr/μA)	α	β (eV^{-1})	E_{cut} (meV)	δ	γ (eV^{-1})	E_ρ (meV)
decoupled	0.6	3.1	2.5	0.08	396	2.6	1.3	203	9.8
coupled	2.9	3.6	2.6	0.04	236	0.7	1.6	173	17

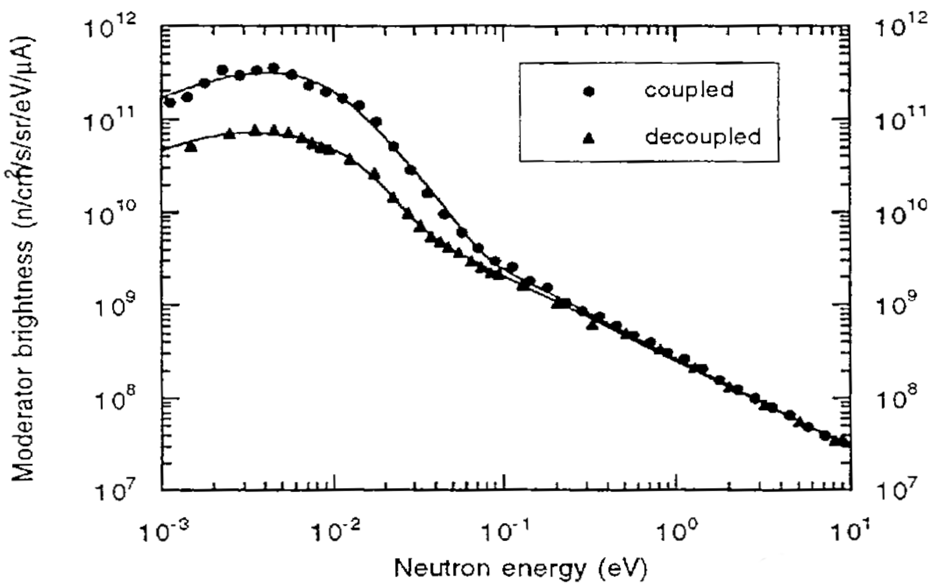

Fig. 3. Average moderator brightness as a function of neutron energy for two liquid hydrogen moderators (50/50 ortho/para mixture).

4. Time spectra

Integral time spectra (10 meV < E < 100 meV) for the three water moderators are presented in Figs. 4 - 6. The units on the time distribution plots are arbitrary because a solid angle of 2 steradians was tallied over to reduce the statistical error associated with each data point. The large solid angle over which the tally was performed does not allow the time-dependent brightness to scale exactly with the steady-state results. However, time constants have been demonstrated to be relatively constant as a function of the solid angle for solid angles up to 4 steradians. Although the units are arbitrary, comparisons can be made between moderators for a fixed energy interval (i.e. the water moderator pulse shapes can be compared directly, as can the LH_2 moderator pulse shapes).

In addition to the data points, which can be used to get an estimate of the full width at half maximum, the exponentially decaying tail of each pulse has been fit and the decay constant is given. From Figs. 2, 4, and 5, the high intensity water moderator results in almost a factor of 4 more intensity than the high resolution water moderator. However, the price for the increase in intensity is approximately a factor of 2 longer decay constant on the pulse tail and an increased full width at half maximum.

The coupled water moderator exhibits much longer decay constants than either of the decoupled water moderators. Several exponentials can be used to fit the tail of the coupled moderator. In Fig. 6, two exponentials have been used as an example. If the data were continued out to longer times, another exponential with a longer time constant would be required to more accurately fit the data.

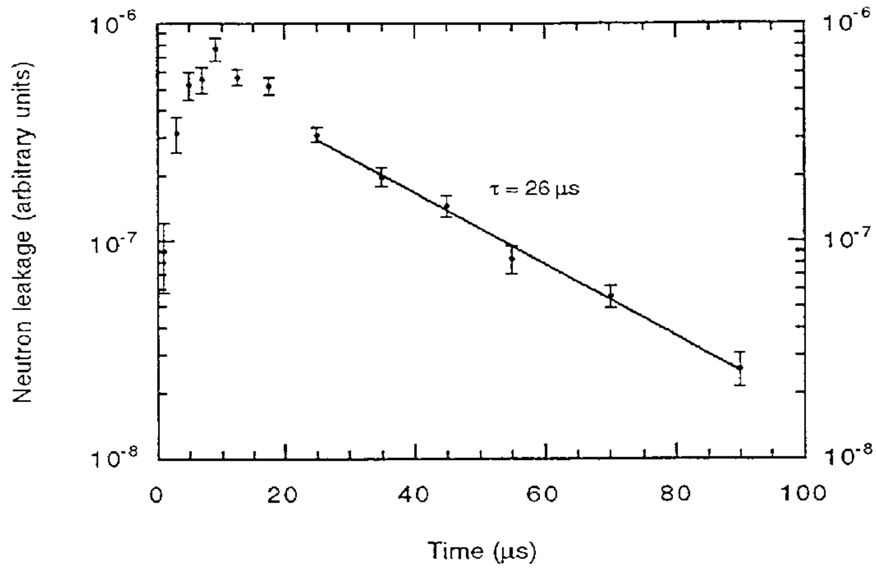

Fig. 4. Time distribution (10 meV ≤ E ≤ 100 meV) from a decoupled high-intensity water moderator for an instantaneous proton pulse.

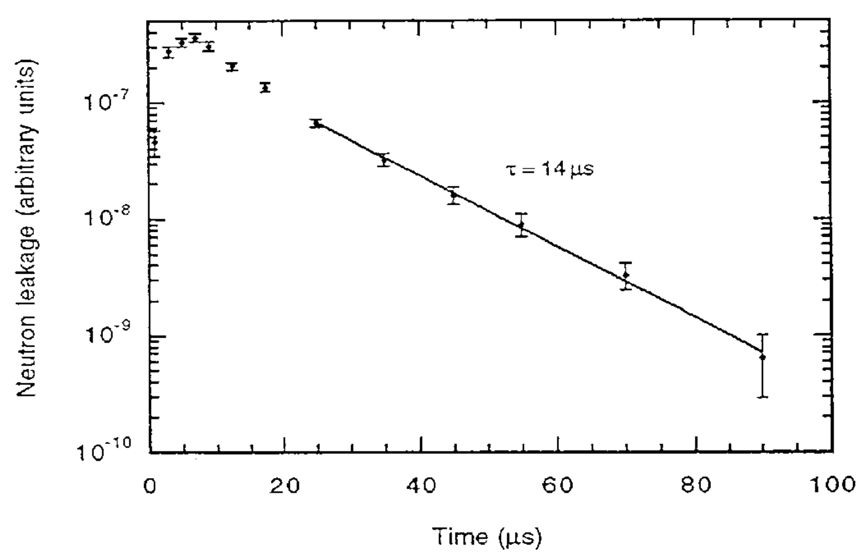

Fig. 5. Time distribution (10 meV ≤ E ≤ 100 meV) from a decoupled high-resolution water moderator for an instantaneous proton pulse.

Time distributions for the liquid hydrogen moderators are shown in Figs. 7 and 8. As expected, the decoupled LH_2 exhibits a time constant much shorter than the coupled LH_2 moderator. The decoupled system is also adequately fit using a single exponential, while several exponentials could be used to fit the coupled system, resulting in different decay constants than those presented here.

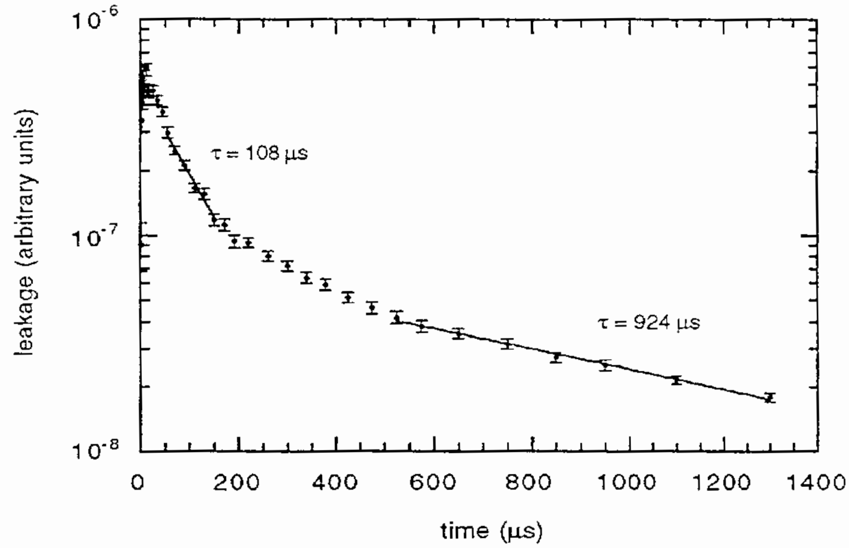

Fig. 6. Time distribution (10 meV ≤ E ≤ 100 meV) from a coupled water moderator for an instantaneous proton pulse.

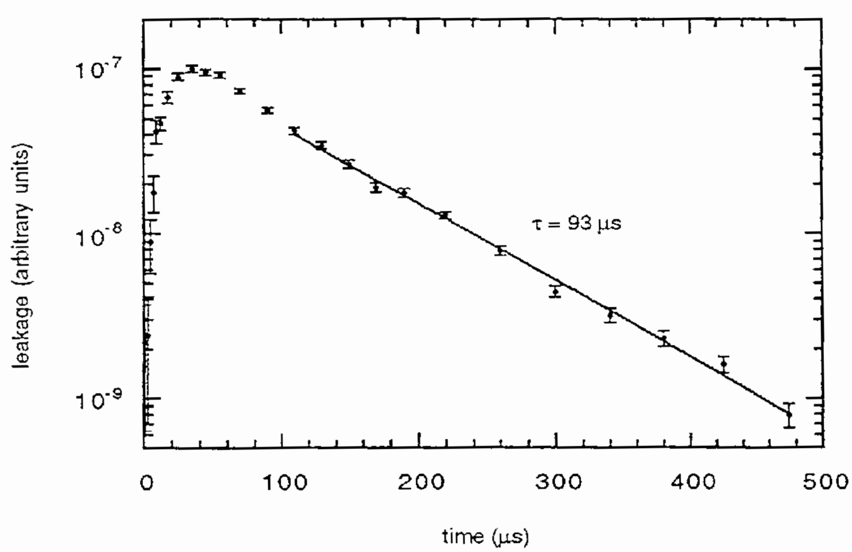

Fig. 7. Time distribution (E ≤ 10 meV) from a decoupled liquid hydrogen moderator for an instantaneous proton pulse.

5. Conclusions

Time and energy spectra have been presented for several moderators of interest to the LANSCE Upgrade project. Semi-empirical data fits for the energy spectra have been completed to aid instrument modeling efforts. This data is intended to support the initial selection of a moderator suite for the LANSCE Upgrade project.

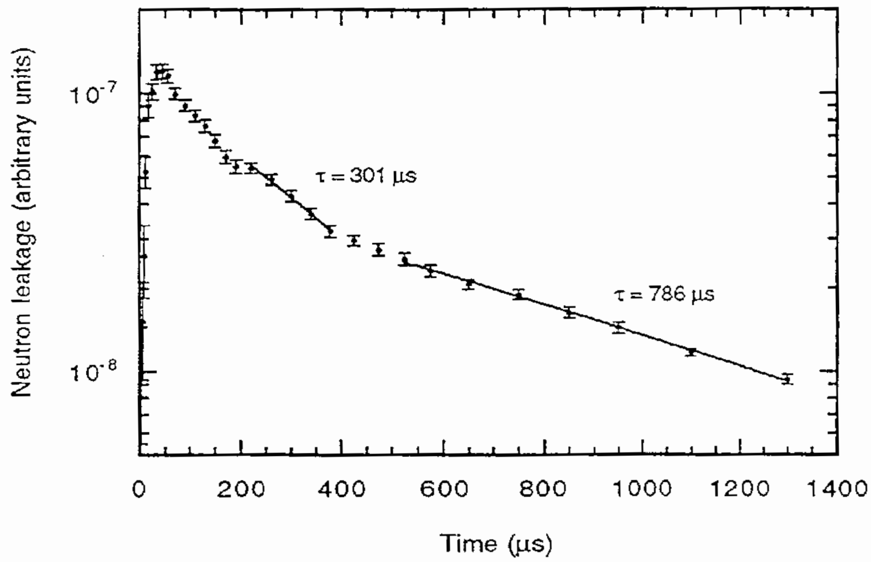

Fig. 8. Time distribution ($E \leq 10$ meV) from a coupled liquid hydrogen moderator for an instantaneous proton pulse.

6. Acknowledgments

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7. References

[1] Macek, Robert J., A Proposal for LANSCE Performance Improvements, Phase II, submitted to the Secretary of the Army, Proposal R-1339-95 (May 3, 1995).

[2] Prael, Richard E. and Henry Lichtenstein, Users Guide to the LCS: The LAHET Code System, Los Alamos National Laboratory Report LA-UR-89-3014 (September 1989).

[3] Carpenter, J. M., et al, Measurement and Fitting of Spectrum and Pulse Shapes of a Liquid Methane Moderator at IPNS, NIM **A234**, 542 (1985).

[4] Duderstadt, James J. and Louis J. Hamilton, Nuclear Reactor Analysis, John Wiley & Sons, NY (1976).

[5] Brun, T. O., et al., LAHET Code System/CINDER'90 Validation Calculations and Comparison with Experimental Data, in Proceedings of the Twelfth Meeting of the International Collaboration on Advanced Neutron Sources (ICANS-XII), T-26 (1993).